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GEOMAGNETIC ACTIVITY AND HALE SECTOR BOUNDARIES.(U)

FEB 80   H LUNDSTEDT, P H SCHERRER, J M WILCOX   N00014-76-C-0207

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By

H. Lundstedt, P.H. Scherrer, J.M. Wilcox

Office of Naval Research
Contract N00014-76-C-0207

National Aeronautics and Space Administration
Grant NGR 05-020-559 and Contract NAS5-24420

National Science Foundation
Grant ATM77-20580

SUIPR Report No. 801

February 1980

INSTITUTE FOR PLASMA RESEARCH
STANFORD UNIVERSITY, STANFORD, CALIFORNIA

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER SUIPR Report No. 801	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) Geomagnetic Activity and Hale Sector Boundaries		5. TYPE OF REPORT & PERIOD COVERED Scientific; Technical rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Henrik Lundstedt, Philip H. Scherrer, John M. Wilcox		8. CONTRACT OR GRANT NUMBER(s) N00014-76-C-0207 NAS5-24420
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute for Plasma Research Stanford University Stanford, California 94305		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Electronics Program Office Arlington, Virginia 22217	(11)	12. REPORT DATE February 1980
		13. NUMBER OF PAGES 16
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (14) SU-IPR-801		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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(12) 20

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Tech; Other

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hale Boundaries
Geomagnetic Activity

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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Submitted to: *Planetary and Space Science*

This manuscript is not yet refereed. It is mailed out when the paper is submitted for publication. The published version is often improved by the refereeing process. This SUIPR report should not be cited after the published version has appeared. We would appreciate receiving any comments that might improve the published version.

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ABSTRACT

The variation of the geomagnetic activity index Ap at the IMF sector boundaries (+ to - and - to +) has been studied for three solar cycles, separating data into vernal and autumnal equinoxes. It was found that a reported increase in Ap as an effect of a Hale boundary can be better attributed to the occurrence of a negative IMF Bz component in the geocentric solar magnetospheric coordinate system and to the occurrence of high speed solar wind streams.

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1. INTRODUCTION

Recently Svalgaard and Wilcox (1976) introduced the concept of "Hale" and "anti-Hale" sector boundaries on the sun. They defined a Hale sector boundary as the half (northern hemisphere or southern hemisphere) of a solar sector boundary in which the change of sector magnetic field polarity is the same as the change of polarity from a preceeding spot to a following spot (Fig. 1). They found that above a Hale boundary the green corona has maximum brightness, while above an anti-Hale boundary the green corona has minimum brightness. The Hale portion of a photospheric sector boundary tends to have a maximum magnetic field strength, while the anti-Hale portion has minimum field strength. Dittmer (1975) found that the number of flares were larger at Hale boundaries for the northern hemisphere. The connection to Hale boundaries for the southern hemisphere was not seen. Calcium plage regions show no preference for the vicinity of boundaries.

A sharp increase in geomagnetic activity after a Hale boundary as compared to after an anti-Hale boundary has been claimed to exist in several studies (Prabhakaran Nayar, 1979; Ohl and Ohl, 1977). We repeated the same analysis with the same assumptions and came to an opposite conclusion. We cannot see any Hale boundary effect in geomagnetic activity. The even and odd solar cycles must be treated separately. The increase in geomagnetic activity can then be explained through the occurrence of high speed solar winds after a sector boundary and through the two equinoctial maxima in geomagnetic activity. The two equinoctial maxima can be explained through the hypothesis by Russell and McPherron (1973, 1974) discussed in several studies (Berthelier, 1976; Mayaud, 1974; Murayama, 1974; Svalgaard and Wilcox, 1978; and Svalgaard, 1975a, 1976).

2. AN APPARENT HALE BOUNDARY EFFECT

During the vernal months, the earth is at the southern heliographic latitude and the solar variations experienced at the earth correspond predominantly to the southern solar heliosphere. Similarly in autumnal months the earth predominantly experiences northern heliographic variations. That would make it possible to study any Hale or anti-Hale boundary effect on the geomagnetic activity from the southern or northern solar hemispheres by studying geomagnetic activity around vernal or autumnal equinoxes. The interplanetary magnetic field sector boundary data (Svalgaard,1975) for each year has therefore been separated into four categories. Negative polarity corresponds to field toward the sun and positive polarity corresponds to field away from the sun.

a) + to - boundary around the vernal equinox (5 February to 5 May),
b) - to + boundary around the vernal equinox (5 February to 5 May),
c) + to - boundary around the autumnal equinox (7 August to 6 November),
d) - to + boundary around the autumnal equinox (7 August to 6 November).

In our study we used IMF-data and Ap-data during three solar cycles 18 (1947-1954), 19 (1955-1964) and 20 (1965-1974). The corresponding Hale and anti-Hale boundaries for the cycles are given in Table 1.

We then analyzed the variation of Ap with a superposed epoch program for the four categories and the three solar cycles separately (Figs. 2-5). After that we averaged Ap for all three solar cycles but separately for Hale and anti-Hale boundaries (Fig. 6). From a result similar to Fig. 6 Prabhakaran Nayar (1979) concluded that the geomagnetic activity increased after Hale boundaries, but that result appears to be in error as shown by the following considerations.

3. AN ALTERNATE EXPLANATION

First we have to notice that an increase in geomagnetic activity does not always follow a passage of a Hale boundary. During the odd cycle 19 geomagnetic activity shows a decrease after the Hale boundary and during the even cycles 18 and 20 geomagnetic activity shows an increase.

Secondly because there are two even cycles and only one odd cycle in the data, and because the even cycle 18 was the most active one, we will by averaging the three cycles together find a larger increase in geomagnetic activity after a Hale boundary than after an anti-Hale boundary (Fig. 6).

A southward-directed interplanetary field Bz component is known to enhance geomagnetic activity (Hirshberg and Colburn 1973). So if there was any difference between Hale boundaries and anti-Hale boundaries in geomagnetic activity, we would expect a southward-directed interplanetary component after a Hale boundary and the opposite for an anti-Hale boundary. To study this we should use the solar equatorial coordinate system, since the Hale boundary effect is an effect on the sun. The result was negative (Fig. 7). If we instead use the geocentric magnetospheric coordinate system we clearly see a southward-directed field during + sector polarity for autumnal boundaries and during - sector polarity for vernal boundaries (Fig. 8). That corresponds to days after a Hale boundary during autumn and also to days after a Hale boundary during spring. This is only true for even solar cycles. On the other hand during odd cycles we would have northward-directed field in the solar magnetospheric coordinates after Hale boundaries. That explains why during the odd cycle the geomagnetic activity shows a decrease after the Hale boundaries.

This is in accordance with the theory of Russell and McPherron (1973), that the quinoxial maxima in geomagnetic activity, observed when days are sorted according to polarity, occurs because the interplanetary magnetic field is ordered in solar equatorial coordinates, whereas the interaction of the solar wind with the earth is ordered in solar magnetospheric coordinates. For a discussion of different coordinate systems see Russell (1971).

High geomagnetic activity also depends on fast solar wind streams, and high solar wind streams are more often located after sector boundaries simply because the high solar wind velocity. That explains why the geomagnetic activity is larger after Hale boundaries compared to times before anti-Hale boundaries even if we have southward-directed IMF in both cases during even solar cycles.

SUMMARY

The geomagnetic response to different polarity changes due to the introducing of the concept of Hale and anti-Hale boundaries, can be explained through changes in Bz-component in geocentric solar magnetospheric coordinates and through changes in the solar wind velocity.

ACKNOWLEDGEMENTS

This work was supported in part by the Office of Naval Research under Contract N00014-76-C-0207, by the National Aeronautics and Space Administration under Grant NGR 05-020-559 and Contract NAS5-24420, and by the Division of Atmospheric Sciences, Solar Terrestrial Research Program of the National Science Foundation under Grant ATM-20580.

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FIGURE CAPTIONS

Figure 1. A Hale sector boundary is the half (northern hemisphere or southern hemisphere) of a solar sector boundary in which the change of sector magnetic field polarity is the same as the change of polarity from a preceeding spot to a following spot.

Figure 2. The variation about sector boundary transits of Ap for Hale boundaries in the southern hemisphere and solar cycles:

a) 18 (1947-1954) (- -)

b) 19 (1955-1964) (· ·)

c) 20 (1965-1974) (—)

The error bar represents two times a typical standard error.

Figure 3. The variation about sector boundary transits of Ap for anti-Hale boundaries in the southern hemisphere and solar cycles:

a) 18 (1947-1954) (- -)

b) 19 (1955-1964) (· ·)

c) 20 (1965-1974 (—)

The error bar represents two times a typical standard error.

Figure 4. The variation about sector boundary transits of Ap for Hale boundaries in the northern hemisphere and solar cycles:

a) 18 (1947-1954) (- -)

b) 19 (1955-1964) (· ·)

c) 20 (1965-1974) (—)

The error bar represents two times a typical standard error.

Figure 5. The variation about sector boundary transits of Ap for anti-Hale boundaries in the northern hemisphere and solar cycles:

a) 18 (1947-1954) (- -)

b) 19 (1955-1964) (· ·)

c) 20 (196501974) (—)

The error bar represents two times a typical standard error.

Figure 6. The variation of Ap averaged over three solar cycles for Hale (—) and anti-Hale (· ·) boundaries.

Figure 7. The variation about sector boundaries of the Bz component in the geocentric solar equatorial coordinate system during time periods:

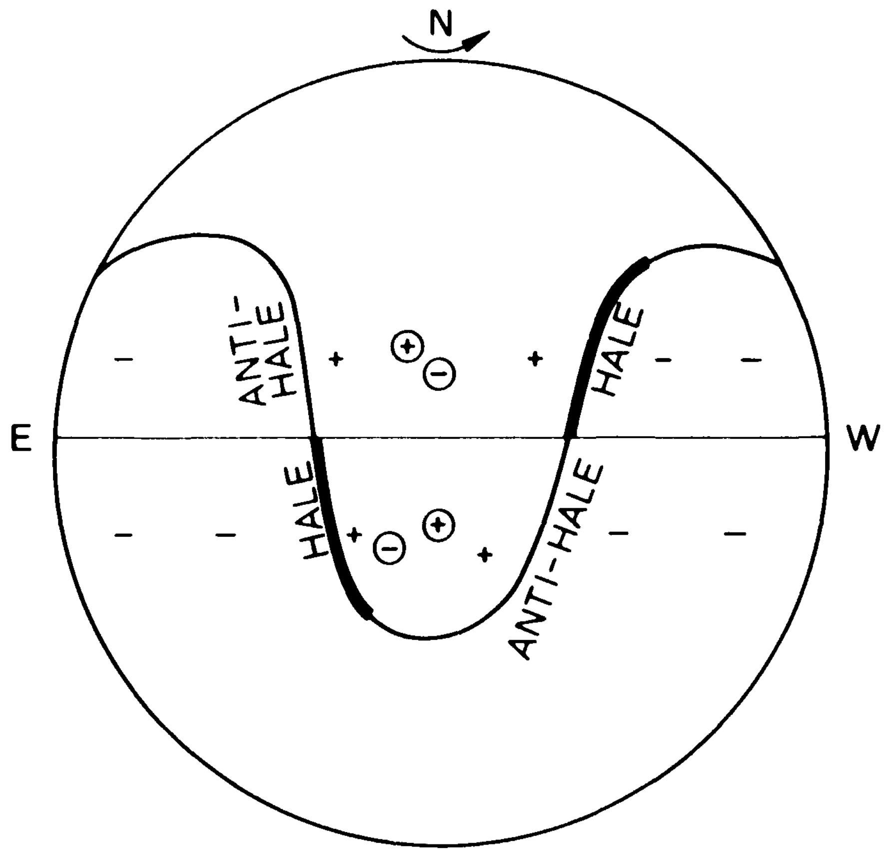
I.	5 Feb. - 5 May	a) Hale boundary (-·-)
		b) anti-Hale boundary (···)
II.	7 Aug. - 6 Nov.	c) Hale boundary (—)
		d) anti-Hale boundary (- -)

Figure 8. The variation about sector boundaries of the Bz component in geocentric solar magnetospheric coordinate system during time periods:

I.	5 Feb. - 5 May	a) Hale boundary (-·-)
		b) anti-Hale boundary (···)
II.	7 Aug. - 6 Nov.	c) Hale boundary (—)
		d) anti-Hale boundary (- -)

TABLE 1

PERIOD	SOLAR CYCLE	NORTHERN HELIOSPHERE		SOUTHERN HELIOSPHERE	
		+ TO - BOUNDARY	- TO + BOUNDARY	+ TO - BOUNDARY	- TO + BOUNDARY
1947 - 1954	18	Anti-Hale	Hale	Hale	Anti-Hale
1955 - 1964	19	Hale	Anti-Hale	Anti-Hale	Hale
1965 - 1974	20	Anti-Hale	Hale	Hale	Anti-Hale



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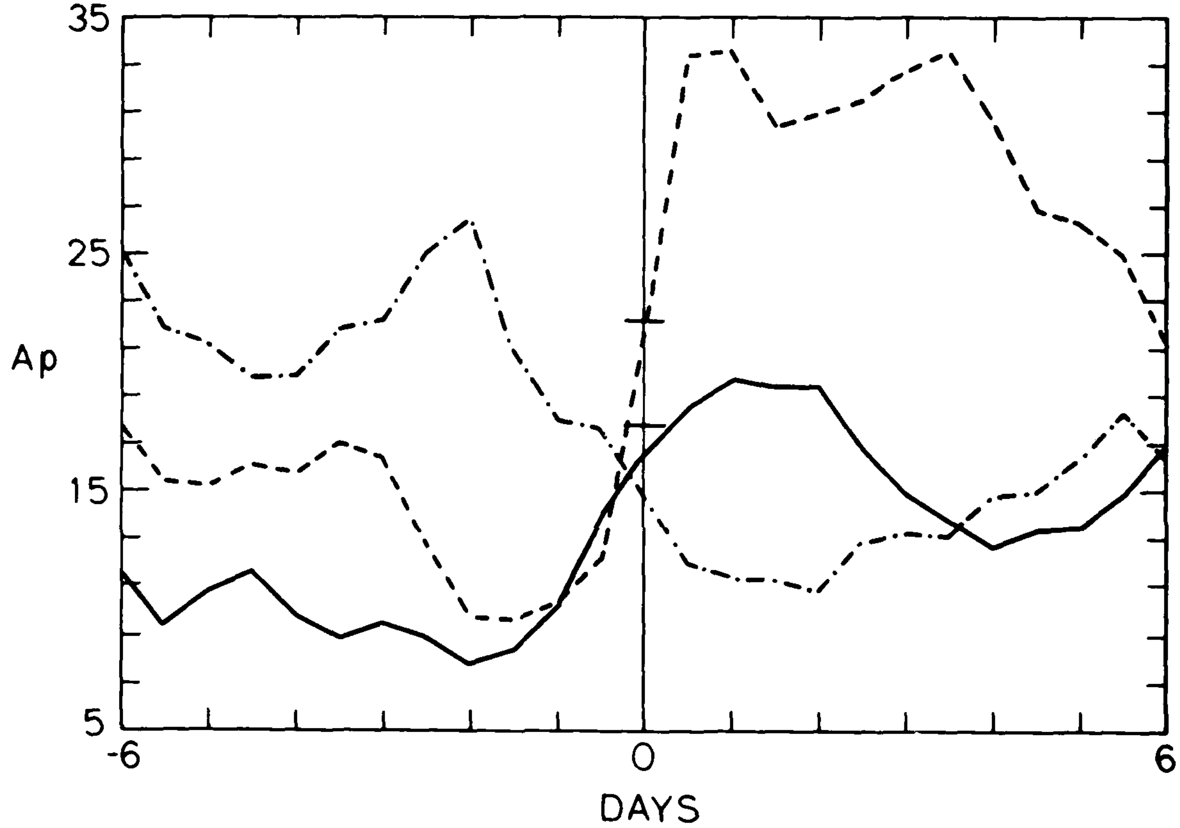


Figure 2

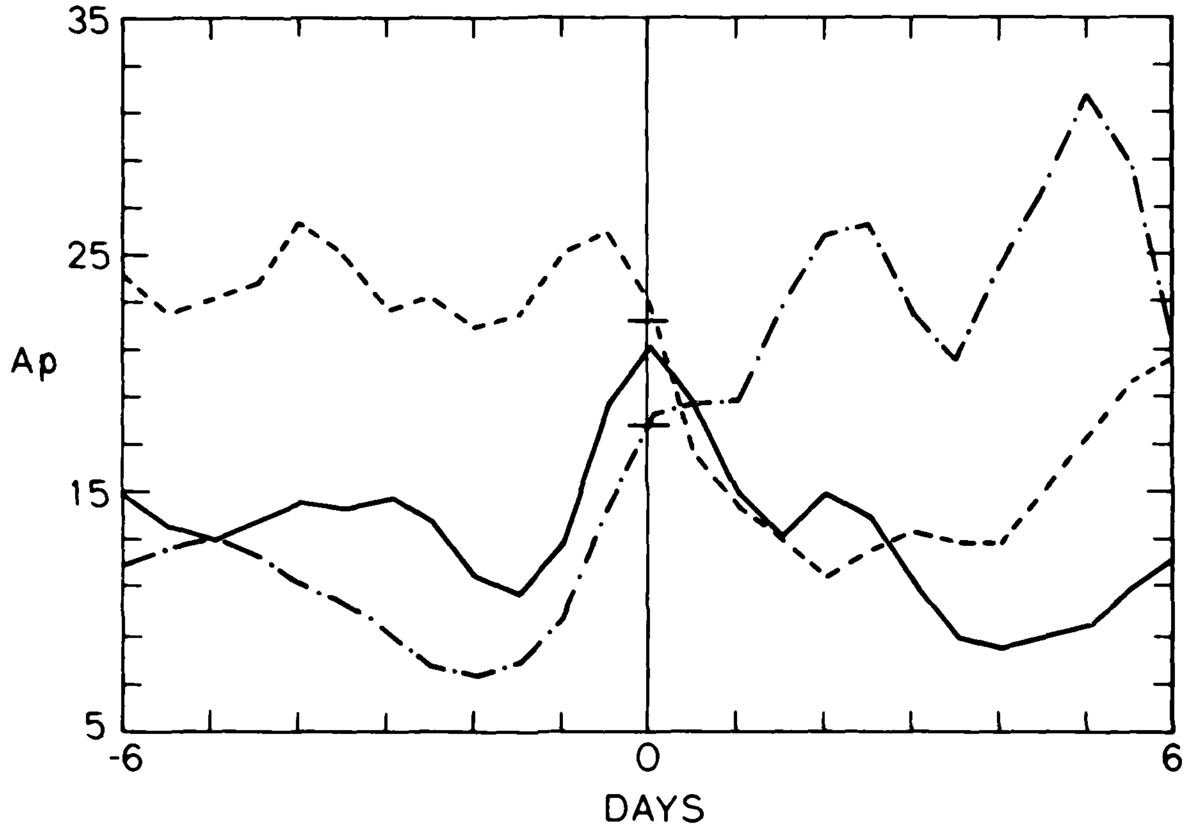


Figure 3

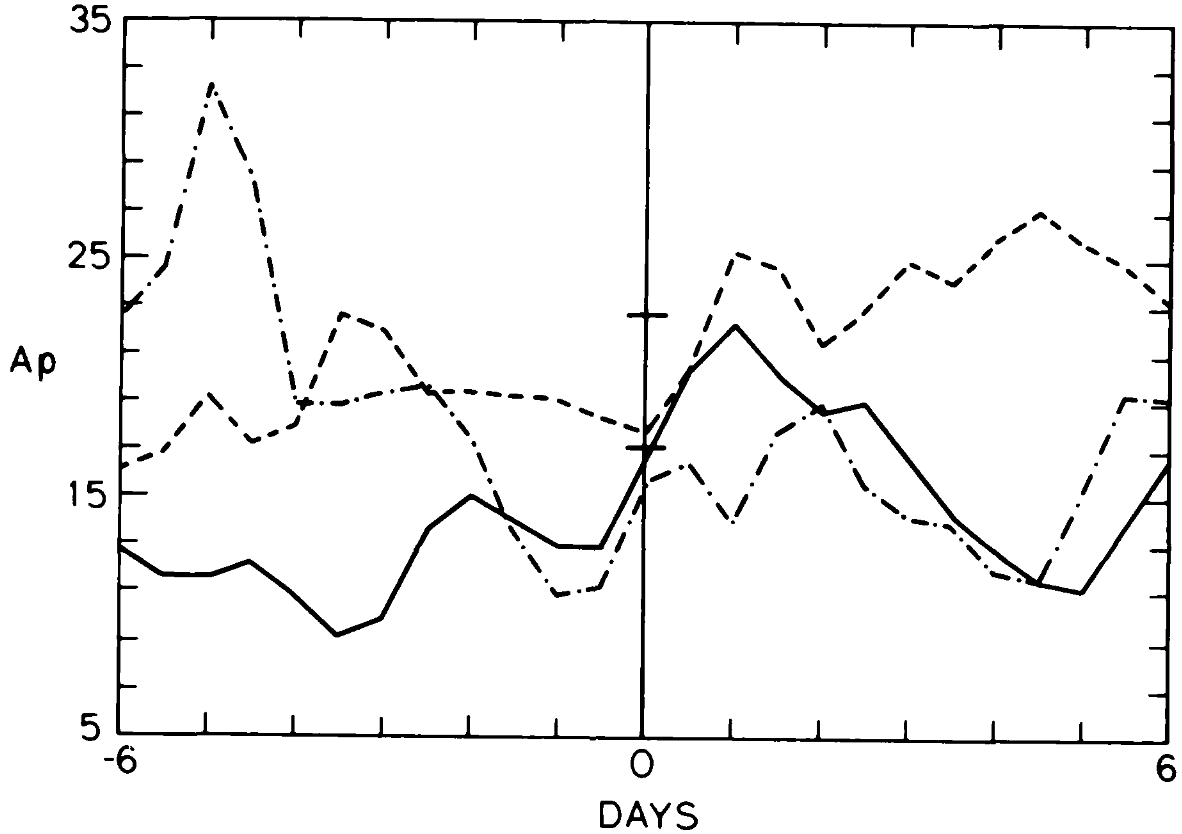


Figure 4

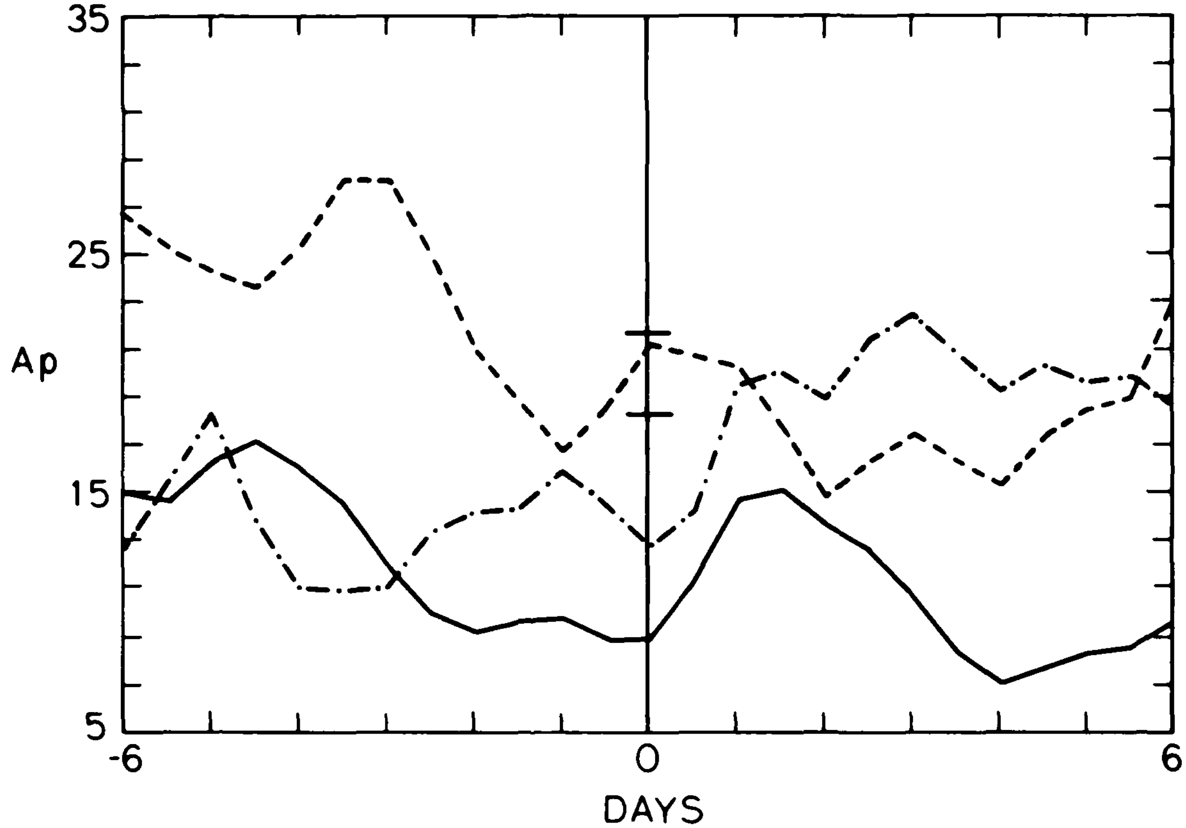


Figure 5

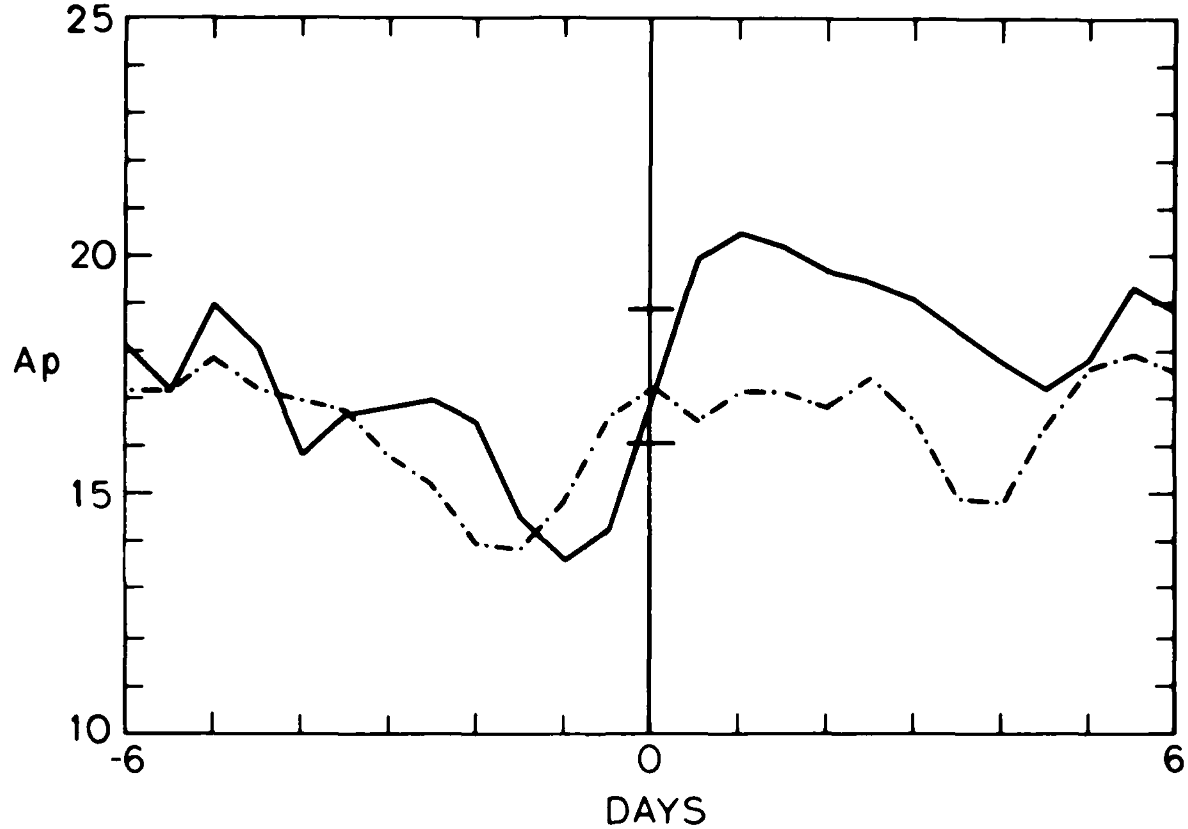


Figure 6

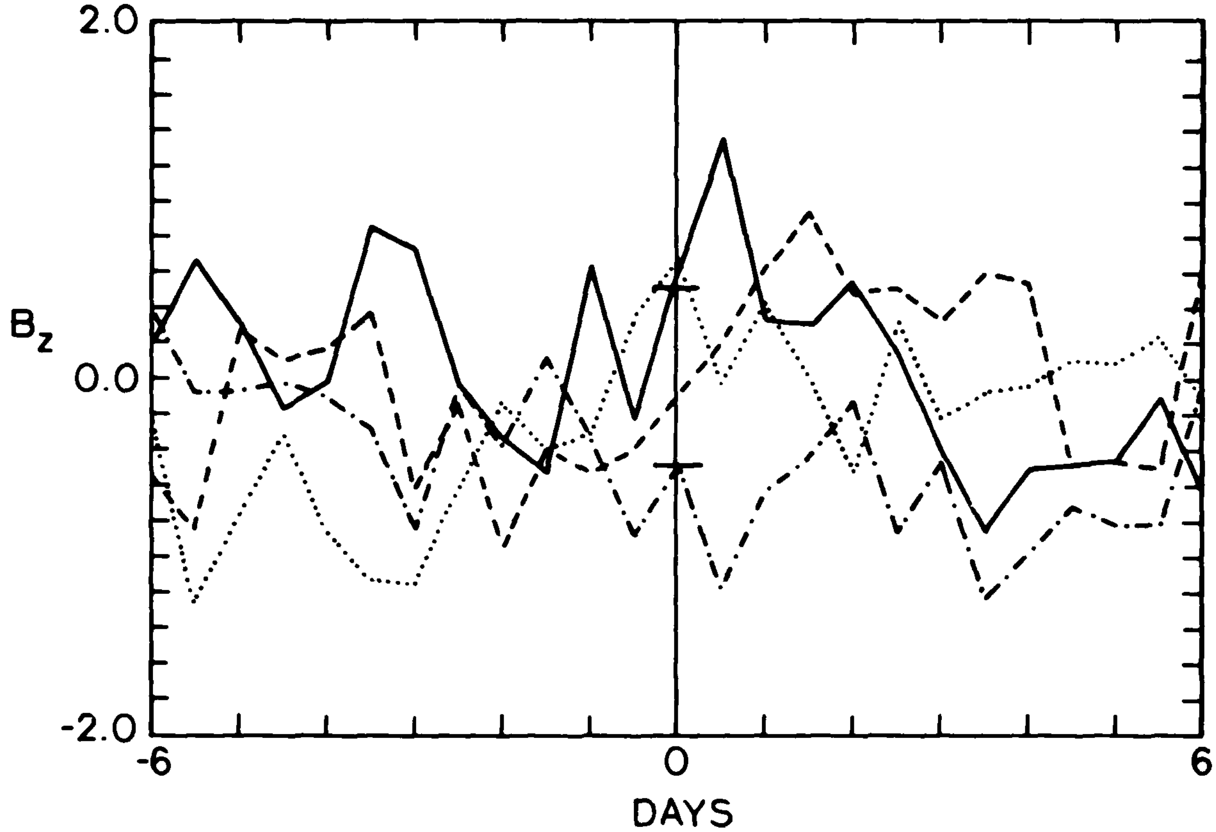
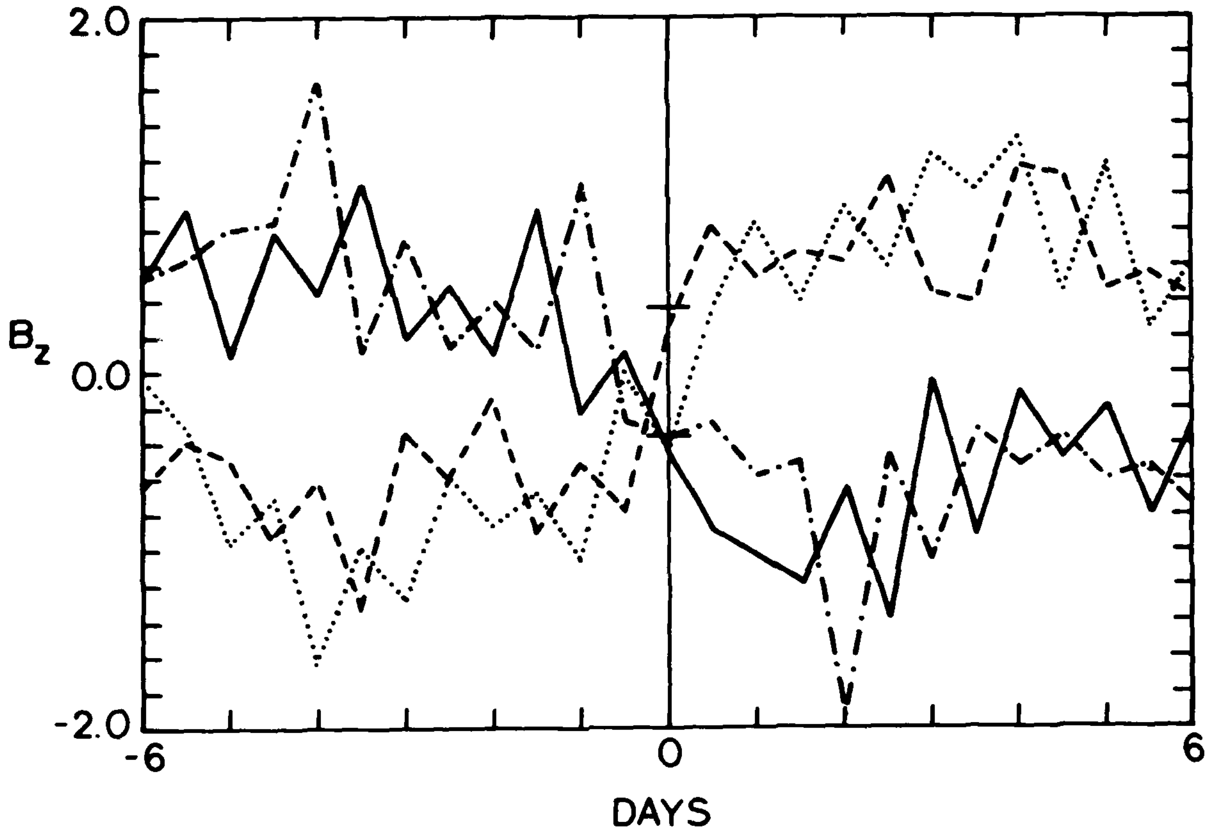


Figure 7



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